Geosyntec consultants

Beech and Bonaparte engineering p.c.

an affiliate of Geosyntec Consultants

CALCULATION PACKAGE COVER SHEET

Client: Gowanus Canal Remedial Design Group (RD Group) **Project:** Gowanus Canal Superfund Site **Project #:** HPH106A

TITLE OF PACKAGE: **SETTLEMENT ANALYSIS OF BACKFILL-LAYER MATERIAL IN TARGETED NATIVE ALLUVIAL REMOVAL AREAS**

PREPARATION	**CALCULATION PREPARED BY:** (Calculation Preparer, CP)	Signature [signed] Name Wassim Tabet, Ph.D.	02 May 2017 Date
REVIEW	**ASSUMPTIONS & PROCEDURES CHECKED BY:** (Assumptions & Procedures Checker, APC)	Signature [signed] Name J.F. Beech, Ph.D., P.E.	02 May 2017 Date
REVIEW	**COMPUTATIONS CHECKED BY:** (Computation Checker, CC)	Signature Clinton Carlson Name Clinton P. Carlson, Ph.D.	02 May 2017 Date
BACK-CHECK	**BACK-CHECKED BY:** (Calculation Preparer, CP)	Signature [signed] Name Wassim Tabet, Ph.D.	19 May 2017 Date
APPROVAL	**APPROVED BY:** (Calculation Approver, CA)	Signature [signed] Name J. F. Beech, Ph.D., P.E.	19 May 2017 Date

REVISION HISTORY:

NO.	DESCRIPTION	DATE	CP	APC	CC	CA
0	TB4 Pilot Study Design – Issued for Bid	05/19/2017	WT	JFB	CPC	JFB

CP:	**WT**	Date:	**05/02/2017**	APC:	**JFB**	Date:	**05/02/2017**	CC:	**CPC**	Date:	**05/02/2017**
Client:	**RD Group**	Project:	**Gowanus Canal Superfund Site**					Project No:	**HPH106A**		

SETTLEMENT ANALYSIS OF BACKFILL-LAYER MATERIAL IN TARGETED NATIVE ALLUVIAL REMOVAL AREAS

INTRODUCTION

The purpose of this *Settlement Analysis of Backfill-Layer Material in Targeted Native Alluvial Removal Areas* calculation package (Package) is to evaluate the estimated settlement of backfill-layer material in Targeted Native Alluvial Removal Areas (TNARA) in Turning Basin 4 (TB4) of Gowanus Canal (referred to as the Canal) under self-weight and after placement of a proposed cap. Specifically, this Package presents settlement calculations to evaluate the potential for compression of the hydraulically placed backfill-layer material under the loading of: (i) self-weight; and (ii) placement of a proposed cap. For the purposes of this Package, the settlement of the backfill-layer material is calculated using one-dimensional consolidation theory. The calculations presented herein do not include the elastic and secondary settlements of the backfill-layer material as they are negligible for granular backfill. Finally, the backfill layer placement requirements are discussed in this Package.

The remaining parts of this Package are organized to present: (i) methodology; (ii) material properties; (iii) analysis results; and (iv) summary and conclusions.

METHODOLOGY

Settlement is related to the increase in effective vertical stresses resulting from self-weight of the backfill-layer material and the placement of the proposed cap. Total settlement has three components: (i) elastic settlement; (ii) primary consolidation settlement; and (iii) secondary consolidation settlement. Since typical backfill-layer materials are sands, the settlement calculations presented herein do not include the elastic and secondary consolidation settlements as they are negligible for granular backfill. The settlement in the backfill-layer materials is assumed to occur through only primary consolidation settlement, which is assumed to be immediate, in this Package. Assuming a normally consolidated backfill-layer material, the consolidation settlement (s_c) can be calculated using one-dimensional consolidation theory as follows:

$$s_c = \frac{C_c}{1+e_o} H_o log \frac{\sigma'_{vo} + \Delta\sigma'_v}{\sigma'_{vo}} \quad (1)$$

where:

C_c = compression index of backfill-layer material;

e_o = initial void ratio of backfill-layer material;

H_o = initial layer thickness of backfill-layer material (feet [ft]);

σ'_{vo} = initial effective vertical stress (pounds per square foot [psf]); and

$\Delta\sigma'_v$ = change in effective vertical stress (psf).

For the purposes of this Package, the consolidation settlement is calculated for two stages: (i) under self-weight of the backfill-layer material; and (ii) after placement of a proposed cap. The settlement calculations for each of these stages are detailed in the subsequent sections. The backfill layer is assumed to have a thickness of 5 ft in this Package and is discretized into five 1-ft thick sublayers for the settlement calculations in each stage.

Stage 1: Consolidation Settlement Under Self-Weight

Changes in the thicknesses of the sublayers of the backfill-layer material occur when the material consolidates under the weight of the sublayer(s) above it. The change in sublayer thickness (s_{c1i}) can be calculated using Equation 1 with σ'_{vo} representing the initial effective vertical stress at the middle of the sublayer of interest and $\Delta\sigma'_v$ representing the change in effective vertical stress due to the weight of the sublayer(s) above the sublayer of interest. The consolidation settlement under self-weight is calculated as the summation of the settlement for each sublayer. The void ratio for each sublayer at the end of Stage 1 settlement (e_{si}) is then calculated using Equation 2:

$$e_{si} = e_o - \frac{s_{c1i}}{H_o}(1 + e_o) \qquad (2)$$

Stage 2: Consolidation Settlement due to Placement of a Proposed Cap

The consolidation settlement in Stage 2 is related to the increase in effective vertical stress due to placement of a proposed cap. The consolidation settlement in Stage 2 is assumed to start immediately after the consolidation settlement in Stage 1 has ended. Therefore, the initial conditions for each sublayer (effective vertical stress and void ratio) for Stage 2 are the same as the conditions at the end of Stage 1. The consolidation settlement of each sublayer due to placement of a proposed cap is calculated using equation (1) with σ'_{vo} representing the initial effective vertical stress at the middle of the sublayer of interest (at the end of Stage 1 settlement) and $\Delta\sigma'_v$ representing the change in effective vertical stress due to the placement of a proposed cap. The consolidation settlement due to placement of a proposed cap is then calculated as the summation of the settlement for each sublayer.

CP: **WT** Date: **05/02/2017** APC: **JFB** Date: **05/02/2017** CC: **CPC** Date: **05/02/2017**

Client: **RD Group** Project: **Gowanus Canal Superfund Site** Project No: **HPH106A**

Backfill Placement Requirements

The specifications are expected to require the hydraulic placement of backfill by dumping from a clamshell or a tremie in order to achieve initial relative densities as described in the subsequent section. Additionally, based on the calculation package entitled "*Results of Simulated Vertical Specific Discharge Rates from the Native Alluvial Sediments at the 4th Street Turning Basin After Dredging, Targeted Removal of Native Sediments, Capping, and Bulkhead Improvements*," the average groundwater flows are upward from the glacial deposits through the native alluvial and soft sediments and into the Canal. Therefore, after the excavation of the TNARA, the placement of large industrial bags (approximately measuring one cubic yard each) of sand-bentonite mix is expected to be required to prevent any uplift or heave from occurring and limit significant increase in TB4 groundwater flow relative to existing conditions.

MATERIAL PROPERTIES

For the backfill-layer material used at the TNARA, the specifications are expected to call for the use of a material similar to the following New York State Department of Transportation (NYSDOT) aggregates (NYSDOT 2008): coarse aggregate types 1B and 1A, Cushion Sand, and Concrete Sand. The grain-size distributions for coarse aggregate types 1B and 1A are shown in Figure 1, and the gradations for Cushion Sand and Concrete Sand are shown in Figures 2 and 3, respectively.

The minimum and maximum void ratios (e_{min} and e_{max}) of sands depend primarily on the particle roundness (R) and the uniformity coefficient (C_u) (EPRI, 1990) and can be estimated using Figure 4. The uniformity coefficient is defined as the ratio of D_{60}/D_{10}, where D_{60} and D_{10} are the grain size diameters, in millimeters, corresponding to 60 percent and 10 percent of particles finer by weight, respectively, on the grain size distribution curve. The range of values for roundness ranges from approximately 0.17 for very angular particles to approximately 0.70 for well-rounded particles (EPRI, 1990). Based on the information presented in Figures 1 through 3, the material selected for the backfill may range from a well-graded material with a uniformity coefficient as high as approximately 10 in the case of Concrete Sand, to a poorly-graded or uniform material with a uniformity coefficient as low as approximately 1.2 in the case of coarse aggregate type 1A. Based on these values, a uniformity coefficient of 1.2 was conservatively selected since it correlates to the highest void ratio (loosest state) and the highest variability (i.e., lower uniformity coefficients correlate to a wider range of possible void ratios), as shown in Figure 4. For the purposes of this Package, the particles of the backfill material are assumed to be subrounded with a roundness value of 0.35. Consequently, using Figure 4, the estimated values for the maximum and minimum void ratios are 0.9 and 0.5, respectively.

CP: **WT**	Date: **05/02/2017**	APC: **JFB**	Date: **05/02/2017**	CC: **CPC**	Date: **05/02/2017**
Client: **RD Group**	Project: **Gowanus Canal Superfund Site**			Project No: **HPH106A**	

As previously mentioned, the specifications are expected to require placement by dumping from a clamshell or a tremie. This placement technique results in relative density (D_r) values of the backfill-layer material between 30 and 50 percent (van‘t Hoff and van der Kolff, 2012). For this Package, an initial relative density of 30 percent was conservatively assumed for the backfill-layer material and the corresponding initial void ratio (e_o) was calculated to be 0.78 using Equation 3:

$$e_o = e_{max} - D_r(e_{max} - e_{min}) \tag{3}$$

The total unit weights of the backfill-layer material and the large industrial bags were assumed to be 115 pounds per cubic foot (pcf). Based on the calculation package entitled "*Geotechnical and Structural Stability of Cap and ISS Soils*" the weighted average total unit weight of the proposed cap was estimated to be 127 pcf. The thickness of the proposed cap was assumed to be 3 ft. The compression index (C_c) for the backfill-layer material was estimated to be 0.04 using a one-dimensional consolidation curve for a normally consolidated poorly graded sand reported in Holtz and Kovacs (1981). This value is consistent with a range of reported compression index values for loose sands (Widodo and Ibrahim, 2012).

ANALYSIS RESULTS

The calculated settlements for each sublayer of the backfill-layer material under self-weight (Stage 1) are presented in Table 1. The total consolidation settlement calculated for Stage 1 is 0.81 inches. The calculated settlements for each sublayer of the backfill-layer material due to placement of a proposed cap (Stage 2) are presented in Table 2. The total consolidation settlement calculated for Stage 2 is 0.67 inches. The calculated factors of safety against uplift or heave for the large industrial bags placed at the bottom of the TNARA are presented in Table 3.

SUMMARY AND CONCLUSIONS

The purpose of this Package was to evaluate the settlement of backfill-layer material in Targeted Native Alluvial Removal Areas (TNARA) under the self-weight of the backfill and due to the placement of a proposed cap. The settlement was estimated for a 5-ft thick layer of backfill material that is similar to NYSDOT aggregates 1B, 1A, Cushion Sand, and/or Concrete Sand. For the analyses and assumptions presented in this Package, the consolidation settlement of the backfill material under self-weight and due to the placement of a proposed cap were calculated to be 0.81 and 0.67 inches, respectively. Additionally, the placement of a single layer of large industrial bags, measuring 3 x 3 x 3 cubic feet each, at the bottom of the TNARA is anticipated to be required to prevent any heave from occurring and limit significant increase in TB4 groundwater flow relative to existing conditions.

REFERENCES

EPRI (1990). *Manual on Estimating Soil Properties for Foundation Design*. Electric Power Research Institute (EPRI), Palo Alto, CA. Report EL-6800.

Holtz, R.D. and Kovacs, W.D. (1981). *An Introduction to Geotechnical Engineering*. Englewood Cliffs, N.J., USA: Prentice-Hall.

NYSDOT (2008). New York State Department of Transportation Standard Specifications, Section 700 Materials and Manufacturing. New York, NY.

van't Hoff, J. and van der Kloff, A.N. (2012). *Hydraulic Fill Manual: For Dredging and Reclamation Works*, volume 244. CRC Press.

Widodo, S. and Ibrahim, A. (2012). "Estimation of Primary Compression Index (Cc) Using Physical Properties of Pontianak Soft Clay," *International Journal of Engineering Research and Applications*, Vol. 2, No. 5, pp. 2232-2236.

Youd, T.L. (1973). "Factors Controlling Maximum and Minimum Densities of Sands," In *Evaluation of Relative Density and Its Role in Geotechnical Projects Involving Cohesionless Soils*, STP 523, ASTM, pp. 98-122.

TABLES

Table 1. Calculated Settlements of Backfill-Layer Material Under Self-Weight

Sublayer Number	σ'_{vo} **(psf)**	$\Delta\sigma'_{v}$ **(psf)**	s_{c1} **(inch)**	e_s
1 (bottom lift)	26.3	210.4	0.26	0.74
2		157.8	0.23	0.75
3		105.2	0.19	0.75
4		52.6	0.13	0.76
5 (top lift)		0	0	0.78

Legend:

σ'_{vo} - initial effective vertical stress at the middle of the lift
$\Delta\sigma'_{v}$ - change in effective vertical stress due to the placement of subsequent lifts
s_{c1} - consolidation settlement under self-weight
e_s - void ratio at the end of self-weight settlement
psf - pound per square foot

Table 2. Calculated Settlements of Backfill-Layer Material Due to Placement of Proposed Cap

Sublayer Number	σ'_{vo} (psf)	$\Delta\sigma'_{v}$ (psf)	s_{c2} (inch)	e_f
1 (bottom lift)	236.7	193.8	0.07	0.73
2	184.1		0.09	0.73
3	131.5		0.11	0.74
4	78.9		0.15	0.74
5 (top lift)	26.3		0.25	0.74

Legend:

σ'_{vo} - initial effective vertical stress at the middle of the lift (end of consolidation settlement under self-weight)
$\Delta\sigma'_{v}$ - change in effective vertical stress due to the placement of a proposed cap
s_{c2} - consolidation settlement due to the placement of a proposed cap
e_f - void ratio at the end of consolidation settlement after placement of a proposed cap
psf - pound per square foot

Table 3. Calculated Factors of Safety Against Uplift of Large Industrial Bags

Water Head (ft)	Water Pressure (psf)	Total Pressure from one Layer of Large Industrial Bags(psf)	Calculated FS Against Uplift
3	187.2	345	1.84
4	249.6		1.38
5	312.0		1.11

Legend:

ft - foot
psf - pound per square foot
FS - factor of safety

FIGURES

TABLE 703-4(1) SIZES OF STONE, GRAVEL AND SLAG											
	Screen Sizes										
Size Designation	**4 in**	**3 in**	**2 1/2 in**	**2 in**	**1 1/2 in**	**1 in**	**1/2 in**	**1/4 in**	**1/8 in**	**# 80**	**#200(3)**
Screenings(2)	-	-	-	-	-	-	100	90-100	-	-	0-1.0
1B	-	-	-	-	-	-	-	100	90-100	0-15	0-1.0
1A	-	-	-	-	-	-	100	90-100	0-15	-	0-1.0
1ST	-	-	-	-	-	-	100	0-15	-	-	0-1.0
1	-	-	-	-	-	100	90-100	0-15	-	-	0-1.0
2	-	-	-	-	100	90-100	0-15	-	-	-	0-1.0
3A	-	-	-	100	90-100	0-15	-	-	-	-	0-0.7
3	-	-	100	90-100	35-70	0-15	-	-	-	-	0-0.7
4A	-	100	90-100	-	0-20	-	-	-	-	-	0-0.7
4	100	90-100	-	0.15	-	-	-	-	-	-	0-0.7
5	90-100	0-15	-	-	-	-	-	-	-	-	0-0.7

(1)Percentage by weight passing the following square openings.
(2)Screenings shall include all of the fine material passing a 1/4 in. screen.
(3)The minus No. 200 material requirements apply only to aggregate for use in portland cement concrete, surface treatment, cold mix bituminous pavements and underdrain filter material.. The test (NYSDOT 201) will be performed on the entire sample of the designated size aggregate. Primary size does not apply in the determination of the minus No. 200 material.

Note:
1. Source: NYSDOT (2008) Standard Specifications, Section 703-02.

Gradation Requirements for Coarse Aggregate Types 1B and 1A

Gowanus Canal Pre-Design Investigation, Brooklyn, NY

Gowanus Canal Remedial Design Group

Geosyntec consultants

Beech and Bonaparte engineering p.c.
an affiliate of Geosyntec Consultants

Ewing, NJ | May 2017

Figure 1

703-06 CUSHION SAND

SCOPE. This specification contains the requirements for cushion sand used for concrete block slope paving.

GENERAL. Material for cushion sand shall meet the requirements specified herein.

MATERIAL REQUIREMENTS. Cushion sand shall consist of clean, hard, durable, uncoated particles, free from lumps of clay and all deleterious substances.
When dry, the cushion sand shall meet the following gradation requirements:

Sieve Size	1/4 in	No. 50	No. 100
Percent Passing by Weight	100	0-35	0-10

The sand may be determined to be unacceptable for cushion sand if it contains more than 10 percent by volume of loam or silt.

Note:
1. Source: NYSDOT (2008) Standard Specifications, Section 703-06.

Gradation Requirements for Cushion Sand

Gowanus Canal Pre-Design Investigation, Brooklyn, NY

Gowanus Canal Remedial Design Group

Geosyntec consultants

Beech and Bonaparte engineering p.c. an affiliate of Geosyntec Consultants

Ewing, NJ | May 2017

Figure 2

703-07 CONCRETE SAND

SCOPE. This specification contains the requirements for sand used in portland cement concrete.

GENERAL. §703-01, Fine Aggregate, shall apply except as modified herein.

MATERIAL REQUIREMENTS. When dry, the fine aggregate for portland cement concrete shall conform to the following gradation requirements:

Sieve Size	Percent Passing By Weight	
	Minimum	Maximum
3/8 in	100	
No. 4	90	100
No. 8	75	100
No. 16	50	85
No. 30	25	60
No. 50	10	30
No. 100	1	10
No. 200 (Wet)	0	3

Note:
1. Source: NYSDOT (2008) Standard Specifications, Section 703-07.

Gradation Requirements for Concrete Sand

Gowanus Canal Pre-Design Investigation, Brooklyn, NY

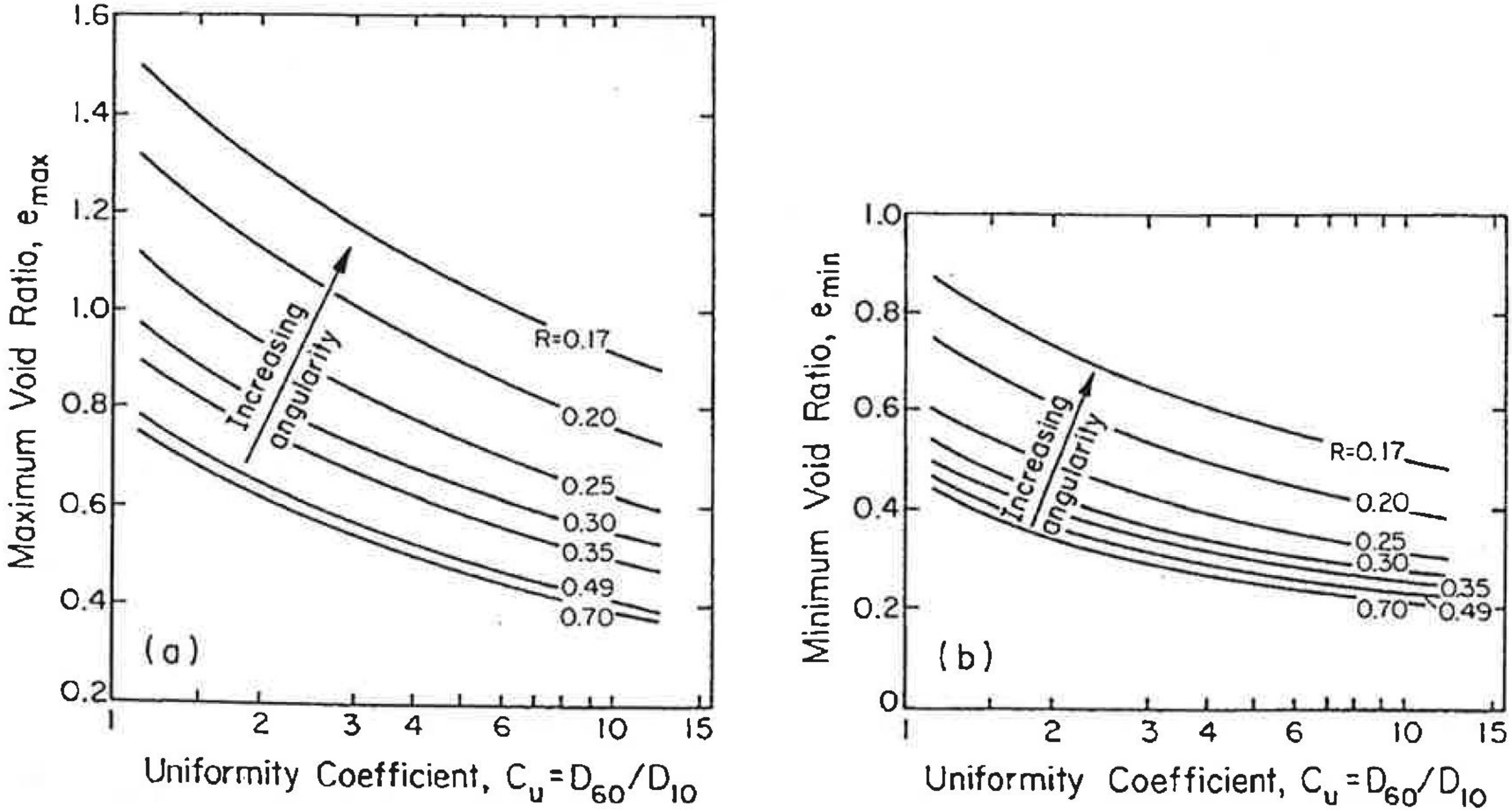
Gowanus Canal Remedial Design Group

Geosyntec consultants

Beech and Bonaparte engineering p.c.
an affiliate of Geosyntec Consultants

Ewing, NJ | May 2017

Figure 3



Note:
1. Source: EPRI (1990).

Generalized Curves for Estimating e_{max} and e_{min}

Gowanus Canal Pre-Design Investigation, Brooklyn, NY

Gowanus Canal Remedial Design Group

Geosyntec consultants

Beech and Bonaparte engineering p.c.

an affiliate of Geosyntec Consultants

Ewing, NJ

May 2017

Figure 4